THE DESIGN FOR A HIGH SPEED DIRECTIONAL INTERCHANGE

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Comments by
[B]ureau of Yards and Docks

(c) "The Design for a High Speed Directional Interchange" by Lt. C. W. Turner, CEC, USN. Various methods for designing of directional interchanges for highways and the analysis of the controlling features of the several methods are included in the thesis. The "spiral-roll interchange transitioned right and left" is also described in "A Policy on Grade Separations for Intersecting Highways" published in 1944 by the American Association of State Highway Officials.

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DIRECTIONAL INTERCHANGE

By

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INTRODUCTION

The happiness of the American people and the welfare of the Nation as a whole are based largly upon the development of our national resources and the proper utilization of the products of American ingenuity.

History has shown that human progress is based largly upon the development of more efficient tools and the employment of these tools in such a manner as to provide maximum benefit to mankind. The automobile is perhaps one of the greatest tools ever developed in all history and its influence has been so great that it has changed completely the economic and social life of the civilized world. More time must pass before its full impact upon the economic and social life of the world can be fully realized.

History fails to reveal any nation achieving greatness that did not attempt to improve its roads to facilitate the movement of persons and goods from one place to another.

Highways have rightly been called "the sinews of civilization".

Today two out of every three families in the United States own automobiles. Billions of hours of human happiness are provided annually to the millions of automobile-owning families in America. Truly, highway transportation has become a great democratic force and has broadened life immensely.

Not only has personalized transportation, brought about mainly by the advances made with the automobile, caused a social and economic revolution which has changed our standards of living but our means and methods of living as well. In fact, it has become an essential part of living!

Actually a new way of life has come into being. Acquaintance-ships and friendships are no longer confined to the individual's

nearest neighborhood. Distant horizons and the pleasures of travel are now within the reach of almost everyone. America has now become accessible to Americans. New highway transportation makes our national senic beauties, our summer resorts and winter playgrounds available to the masses, where before they were a priviledge enjoyed only by the wealthy and those few residing in their immediate vicinity. This aspect of personalized transportation has ironed out distinctions in class and has erased many social barriers.

The highways have always been the arteries of trade of a nation and because of the great improvements in transportation methods brought about by the advent of the automobile, the highways now have an even closer relationship to the economic welfare of the people than ever before.

The movement of automobiles is often of a business nature. Men and women go to and from work in their cars. Countless salesmen, rural letter carriers and others engage in earning a livelihood use passenger cars to get about.

Every other means of transportation is absolutely dependent upon road transportation for the beginning and completion of the journey. Modern highway transportation has brought the farmer nearer to his markets and has greatly increased his trading radius.

Improved highways and motor vehicles have been of inestimable value to all communities; but this is particularly true in the case of those cities and towns that depend entirely upon highway transportation for their contact, communication and intercourse with the outside world. There are many such communities that have no railroad service and are entirely dependent on motor transportation and without this facility they could not exist.

One economic item that must not be overlooked is the increase in land values, both urban and rural, and the resulting increase in the taxing base, brought about by improved highways. Uncounted sections of agricultural lands have been transformed into attractive residential villages. The broad lawns, clean air and bright sunshine of these suburban homes have attracted more and more city dwellers who now commute to and from their daily work by motor vehicle.

De-centralization of industry may be an evolutionary change that brings about certain local and temporary disadvantages. However, such changes are of real service and lasting importance to the country as a whole. Great congestions of population and industry are conducive to degrading social conditions, a lowering standard of health, higher transportation costs and reduced efficiency in distribution.

The military defense of a nation is one of the national government's first and foremost duties and all great military figures of history have recognized the necessity of adequate roads for our national defense network. Now, as never before in history, higways take a new and more important meaning in the military scheme of things. In years past, the extensive development of highways have been opposed by some on the basis of providing good inroads into the heart of the country for an invading enemy. This danger, though it was used to full advantage by the Allies in the defeat of the Axis in the past war, no longer is of any real consequence. With the introduction of the atomic bomb into warfare, it has become a military necessity to use the highways as a means of moving large numbers of people in relative short intervals of time from the congested areas to prevent their annihilation in mass. So long as the great-power relations show symptoms of chronic instability, reduction to the vulnerability of attack in any manner whatever commands our immediate attention, however reluctant.

Thus we see that highways' influence, social, economic and military alike, on the nation as a whole is unusually important to the welfare of the people of the United States as individuals.

The providing of an adequate highway network is a proper function of government and in keeping with this function, the late Franklin D. Roosevelt on 14 April 1941 appointed a committee, to be known as the National Interregional Highway Committee, "to investigate the need for a limited system of national highways to improve the facilities now available for interregional transportation, and to advise the Federal Works Administrator as to the desirable character of such improvement, and the possibility of utilizing some of the manpower and industrial capacity expected to be available at the end of the war."

By doing things better and more efficiently, living standards are advanced and the higher the standards of living of a nation advance, the greater the need of highways. Adequate highways free a nation from economic stagnation, enrich its social life and thus elevate its standards of living.

It is to this end that road designers must look. They must be guided by the past, of course. They must use the present as a point of departure for predicting the future inovations and developments necessary in highway design to remain abreast of the rapid strides made by the automotive industry. At the same time, he must not be afraid to accept a new idea or inovation even though it may mean discarding an old idea that is usuable but which has a very definite limitation or is basically bad. On the highway engineer's shoulders rests the safety and comfort of millions of Americans. To think and act contrary to this, is to waste, for a time, the technological progress made in the transportation medium involved.

It has been admitted by some, without to much loss of face, that highway developments have not kept pace with the technological advances made in the automotive field. The fault, however, does not lie in the professional ability of the highway engineer; but rather in the very definite limitations imposed upon him by economic, financial and political interests.

To see the interregional highway system as proposed by the National Interregional Highway Committee is one thing. To try to realize and visualize its affect on American life is still another. In peace, a bloodstream over which Prosperity will travel. In war, an escapeway over which Mankind will travel to maintain a way of life.

Wherever two of these main arteries cross, whether urban or rural, there exists the unsolved problem of "directional interchange" which if solved practically, would provide rapid and continuous flow of traffic in times of peace and war.

It is with the analysis and solution of this problem of "directional interchange" that the author shall concern himself in the pages that follow.

The cry, now and always, seems to be "Speed and more speed".

"Coast to Coast...at a SAFE 70" is not just another pipe dream. It is within this sphere that the "directional interchange" belongs, for without its solution Mercury again returns to his spatial position in the mind of Man.

OBJECT

This thesis is the result of thought precipitated by an article appearing in the June issue of SCIENCE ILLUSTRATED entitled "Coast to Coast——at a safe 70" by Myron Stearns.

The article mentioned above discussed directional interchange as one of the many unsolved problems of the road designer. It gave illustrations of the solution by using a traffic circle—"safer than the stop sign, is inefficient, costly, wastes space", and the cloverleaf—"confuses drivers who have to turn right to go left". Also shown was a "new solution" which would be very costly to construct due to an excessively long retaining wall on each side of the two upper level through traffic lanes and is even more wasteful of space. However, it would handle a greater volume of traffic at a higher speed providing its lack of symmetry on left turns does not tend to confuse the driver and slow down movement through it.

The purpose of this thesis is to make a study of the directional interchange problem and try to devise some practical design for a directional interchange that will overcome the main disadvantages of the cloverleaf; namely, inefficient use of space, excessive distance of travel on the left turn and confusion to the driver entailed by having to turn right to go left.

It is also the author's purpose to restrict himself to two levels of traffic flow, provide for an overall speed of fifty miles per hour minimum through the interchange, allow no grade to be greater than five percent, avoid the use of broken back curves, and try to avoid the use of reverse curves where possible but where absolutely unavoidable insert spirals each side of the point of reversed curvature to make the transition as easy as possible on the driver.

The directional interchange designs studied by the author in the course of preparation of this thesis were considered to be

original with the author. However, upon receipt of the September issue of SCIENCE ILLUSTRATED, the first thing to catch his eye were two of the letters to the Editor containing two of the designs studied, one of which was exactly the same as the one to be designed here. The design was submitted by Mr. Stan Feld of New York, New York and did not appear to have been designed for high speeds and less than five percent grades on the right and left turns. The design proposed by Mr. George B. Cluett of Little Compton, Rhode Island would require a great deal of space, give a very inefficient utilization of that space. In addition, it contains one very serious limitation that would make the interchange ineffective at high speeds; namely, left-traffic must cross when coming on or turning off the through-traffic lanes.

However, there is one important thing that the author feels can be drawn from such a similarity of thought. The problem of directional interchange, when restricted to a definite number of traffic flow levels, be it two, three or four, is so controlled by its limitations that there are only a few favorable solutions possible and after a period devoted to the study of the limitations involved, the results will be exactly the same.

In another sense, this coincident, disconcerting as it was to the author at first, does show that People are interested in other people's problems even though they may be outside their own chosen field or profession, which in itself is a very healthy mental attitude.

ANALYSIS

Mr. Leslie Williams states in his article, "What can be done about Traffic",..."The possibility of completely integrating express highway facilities within the overall plan of the American City is only now taking form. Those cities that have as their objective the development of reasonable freedom of traffic movement, the removal from the street system of traffic detrimental to community life and the orderly development of new facilities dependent on modern methods of transportation, will feature the modern parkway and expressway in their construction programs."

The incorporation of these systems into the overall plan by the N.I.H.C. will mean the employment of a large number of interchanges throughout the United States and a practical solution is necessary now in order to avoid increased engineering expense to the project as a whole and provide the American people witha standard interchange that will be compatible with their way of life and the same, whether located in California or New York State, so that once they learn its purpose and interworkings they will find their route by following large, clear, concise signs, approach the interchange at high speeds with confidence, and be conscious that they are a part of the resulting smooth flow of traffic rather than a confused part of what was once a maelstrom.

To accomplish this certain considerations are necessary since it has been estimated that some 40,000,000 vehicles will be on the highways by 1960.

These considerations can be based on the following basic principles: SAFETY, for protection to oneself and property and to others; CONTINUOUS FLOW, for comfort and convenience; SPEED, for time saving and quick arrival and ECONOMY, for a saving in expense to the vehicle operator as well as to the government building and maintaining the right-of-way.

SAFETY

Adequate interchange provides ease in handling large week-day business-boards and large week-end pleasure-seeking throngs leaving or returning to metropolitan centers and in a fractionof the former time with added safety. This dramatically demonstrates the importance of the interchange in the development of motor transport.

Various features are incorporated to guarantee this safety since the large number of accidents normally from traffic demands increased care in the designing of highways.

The elimination of all grade crossings is necessary in order to eliminate cross-interference. Divided highways or highways considered as separate highway systems entirely are necessary to eliminate medial interference, as well as reducing internal interference. The utilisation of deceleration and acceleration lanes is necessary in order to reduce the marginal interference.

Adequate signs should be provided and efficient use of them should be made. In high speed highway design it will become necessary to place direction on the highway wearing surface or on large signs over the road at the approaches to an interchange. Signs should be placed well back of a turn off lane in order that cars can change to the correct traffic lane. Since it is impossible to read more than two towns on the same sign when passing at high speed it is useless to put more. The development of "parkway lights" is a necessity since it is damaging to a drivers' eyes to be facing the bright lights of the opposed-traffic stream for long periods of time and make it hard to make out the road ahead as well. Lights that are aligned on the center line or the use of hedges along the median strip when two highways are close together would eliminate this hazard and nuisance.

There is general agreement that sound safety regulations should be improved; but these improvements must avoid two things. One, they must not tend to limit speed nor slow down traffic flow in any manner

the aftermath "back-up" congestion will be avoided.

Direct interchange for the through traffic streams leads to spreading the one-way roads near a grade separation structure to the extent that the highway designer finds that he is no longer dealing with the center line of a divided highway but instead is using separate aligment and profiles for one way roads.

From his experience in the design of the Pentagon Road System and other networks of the express type of highway, Mr. Joseph Barnett found that "Experience...leads strongly to the conclusion that the entire concept of 'divided highways' or 'double-barreled highways' or 'highways with parkway medians' or whatever they may be called, should be discarded in metropolitan areas in favor of a system of one way roads."

This would free the designer and encourage him to think in terms of smooth-flowing, streamline, direct traffic movements.

SPEED

Speed has long been a factor of prime importance in the life of man. Since the advent of the machine age, he has greatly increased his tempo of life. With increased speed, comes increased hazard. For now, 70 miles per hour seems to be the maximum to be considered as far as highways are concerned.

ECONOMY

Low annual cost is a major consideration in the choice of concrete pavement as a wearing surface.

Each progressive design, though it may mean additional first cost, it also means added safety to lives and property and in that way partially justify the additional expense involved. Too, an interchange is a small part of a large over all design whose proper functioning depends to a large extent upon the adequacy of the interchange. A chain is only as strong as its weakest link. To draw a parallel, it would seem that additional expense would be

since this is contrary to the general trend—speed. Two, sub-systems of roads inside the interchange should not be provided for people who make mistakes in the interchange, since once confused person inside the interchange represents a hazard to all others passing through the interchange at that time. Economically, the added expense for such a sub-system is not warranted and a person who does not know where he is going or how to get there should not be on the highway making high speed for he is nothing short of an "accident, looking for some place to happen". It would be better to provide "pull-over zones" outside the limits of the interchange where unfamiliar drivers could pull over and study signs and directions to their destination and then continue on their way.

For safety, simplicity should be the keynote of design. In testing a road network for simplicity, it is unwise to view it as a whole, which cannot actually be done except from the air. The driver sees only the road that lies ahead, the various points of entrance and exit, and the direction signs. If the route from the origin to his destination is easy to travel, direct in character and free of sections that might confuse the driver, it is simple in design regardless of how it may appear on paper.

CONTINUOUS FLOW

The express highway has become an economic necessity where heavy concentrations of motor vehicles must be handled. Wasted hours, millions of them, result from congestion on highways that do not have the capacity for steady flow of large volumes of traffic.

The interest now is not so much in higher speeds on the highways, that is speeds above 50 miles an hour, but rather in continuous flow of traffic, since traffic congestion retards business and civic growth.

Roadway intersections must be considered in terms of their capability and capacity to accommodate the peak loads to which they are or will be subjected to. If designed for peak load the

warranted just to "strengthen the link".

ADVANTAGES CLAIMED FOR THE "SPIRAL-ROLL" TYPE OF DIRECTIONAL INTERCHANGE

For large volumes of traffic changing its course at an intersection at high speeds, the usual types of interchange structures, such as the cloverleaf and the widely spread intersection, would not be appropriate and decidely inefficient. A cloverleaf at best not the solution, since the high cost of right-of-way militates against the use of either the cloverleaf or the other widespread types.

The "spiral-roll" design gives minimum length of travel for interchanging traffic, adequate capacity for large numbers of vehicles during peak periods, and simplicity in design, providing natural paths of travel.

The feature open to the most criticism will be the use of eight bridges and the justification of their expense. Without further study, no justification can be given except that, ifsome of the interchanges proposed are considered economical and are to be built, then this design is just as economical and just as practical.

50 M.P.H.

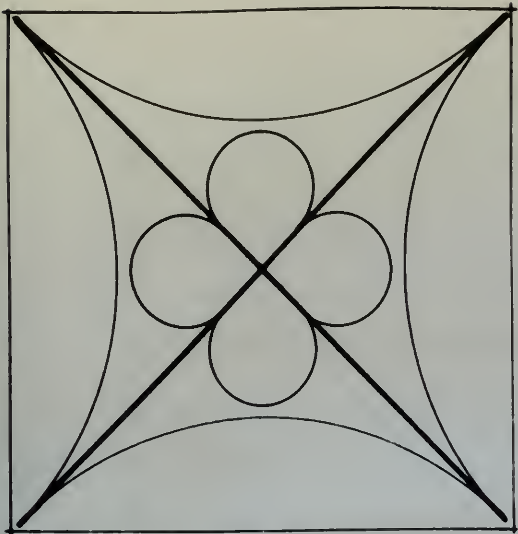


Fig. 1 Cloverleaf

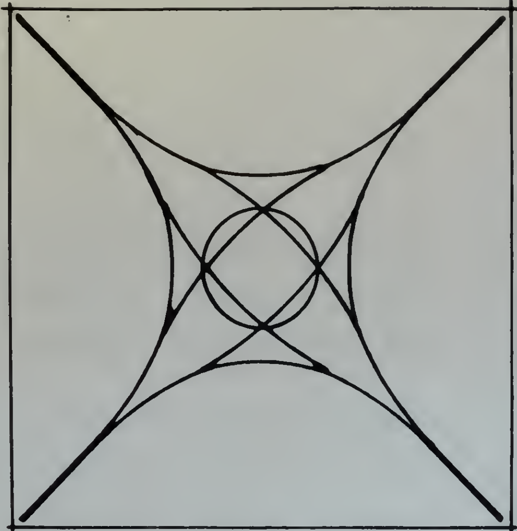


Fig. 2 Basket-weave with left turning circle

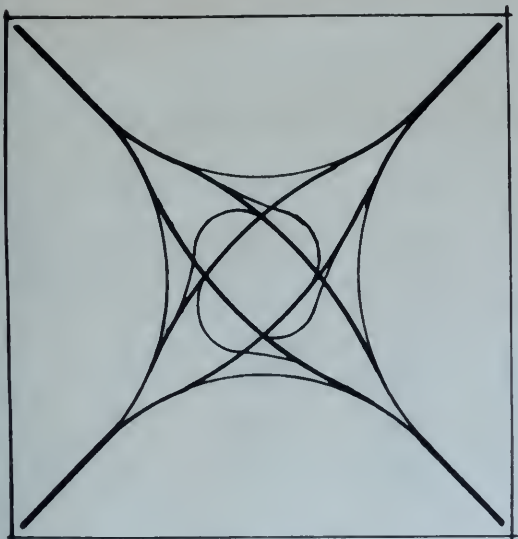


Fig. 3 Basket-weave with transitioned left

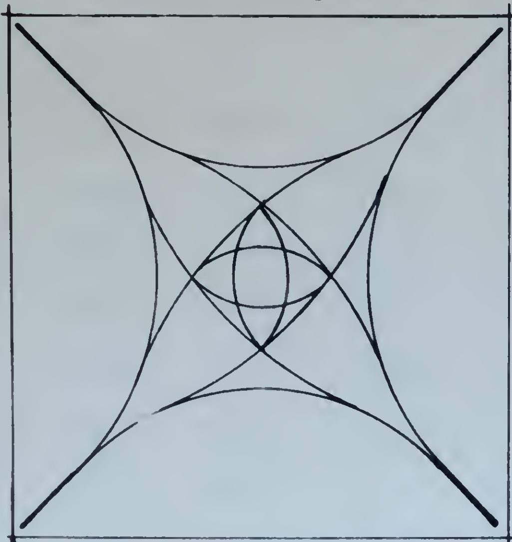


Fig. 4 Double Basket-weave with transitioned left

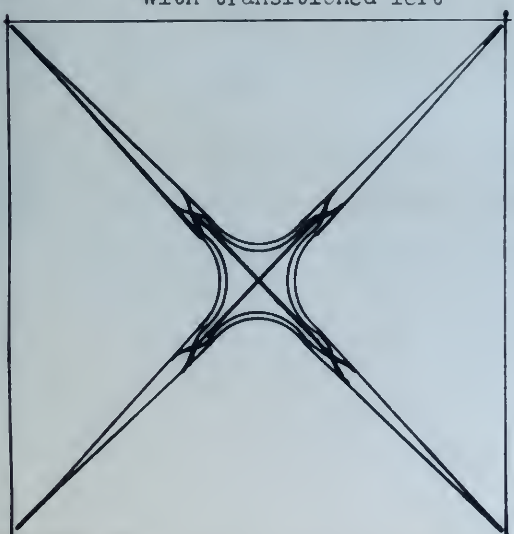


Fig. 5 Spiral-roll circular right and left

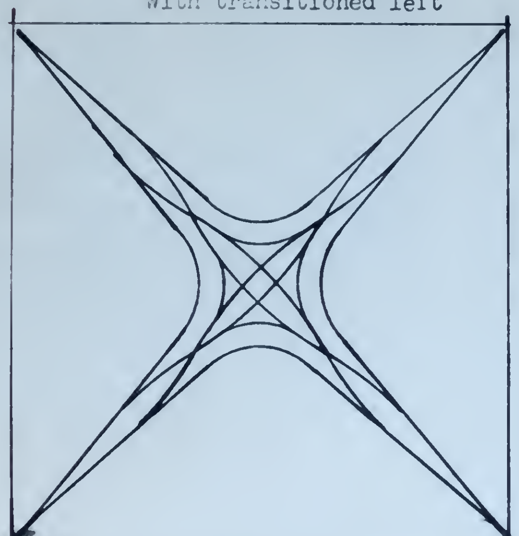


Fig. 6 Spiral-roll transitioned right and left

ANALYSIS DATA

	MPH	FIG. 1	FIG. 2	FIG. 3	FIG. 4	FIG. 5	FIG. 6
TOTAL AREA in square feet	70	8,650,000	3,130,000	3,130,000	3,130,000	2,620,000	2,000,000
	60	4,230,000	1,762,000	1,762,000	1,762,000	995,000	1,500,000
	50	2,230,000	1,090,000	1,090,000	1,090,000	635,000	1,000,000
AREA OF RIGHT-OF-WAY in square feet	70	1,248,000	750,000	750,000	750,000	670,000	1,165,000
	60	870,000	564,000	564,000	564,000	480,000	500,000
	50	630,000	444,000	444,000	444,000	360,000	825,000
EXCESS AREA REQUIRED	70	7,402,000	2,380,000	2,380,000	2,380,000	1,950,000	835,000
	60	3,360,000	1,198,000	1,198,000	1,198,000	515,000	500,000
	50	1,600,000	646,000	646,000	646,000	275,000	175,000
LENGTH OF THROUGH-TRAFFIC LANE in feet	70	4,160	2,500	2,550	2,950	2,220	3,850
	60	2,900	1,880	1,880	2,210	1,592	3,000
	50	2,100	1,480	1,480	1,790	1,194	2,745
LENGTH OF RIGHT-TRAFFIC LANE in feet	70	4,460	2,800	2,800	2,800	3,200	2,150
	60	3,300	2,280	2,280	2,280	2,500	1,500
	50	2,500	1,980	1,980	2,200	2,200	1,189
LENGTH OF LEFT-TRAFFIC LANE in feet	70	8,600	2,150	2,550	2,350	2,800	1,780
	60	5,825	1,450	1,760	1,650	2,280	1,350
	50	4,050	1,010	1,250	1,100	1,980	970
TOTAL LENGTH OF TRAFFIC LANES in feet	70	78,080	29,800	31,400	32,400	32,880	31,120
	60	48,110	21,640	23,680	24,560	25,488	23,400
	50	34,600	17,880	18,840	19,480	21,488	19,616

CLOVERLEAF

The main faults of the cloverleaf have already been discussed and the only reason for repeating them here is for the purpose of comparison with the designs studied. The main disadvantages at high speeds are the confusion caused the driver by having to go right to turn left, the excessive area required, wasteful utilization of this space and excessive distance of travel on the left turn. Its one advantage over all other designs is the fact that one bridge is all that is necessary to separate the traffic lanes.

BASKET-WEAVE
With Left Turning Circle

This design requires four bridges to make the traffic separations. It demands excessive area also; but the reason for discarding this type of solution was the fact that left-traffic might try to cross the through-traffic lanes to correct a mistake made in direction. The main reason for developing this type was to limit the number of bridges to four.

BASKET-WEAVE
With Transitioned Left

Limiting the design to four bridges and using transition on both ends of the left turns increased the area more than was desired. Designs with eight and twelve bridges were studied and the best solution obtainable by this method is using four bridges for the through-traffic and four skewed tunnels for the transitioned far end of the left turn, taking the left turn near transition off after passing under the last through-traffic bridge. The use of eight bridges and the excessive area requirements were the reasons for discarding this type of design.

No grade limitations were found in any of the designs above 50 mph; but when speeds below 50 mph were studied, grades went above the 5 percent limitation imposed on all designs.

DOUBLE BASKET-WEAVE
With Transitioned Left

This design is similar to the designs shown in Figs. 1 and 2, differing only in that the left turns are made in the area inside the through-traffic lanes. Eight bridges of the same degree of skew would be required to do this. The most serious limitation on this type of design, outside the excessive area required, is the steeper grades necessary. All grades on the left turn are down grades and the distance between the inner network bridges rules the entire size and shape of the design.

It was again necessary to discard a design due to definite and undesirable limitations. At this point, though, one fact was apparent—no satisfactory system could be designed with less than eight bridges as long as the design was limited to two levels of traffic and as long as left turns had to turn left.

SPIRAL-ROLL
Circular Right and Left

An entirely different approach to the problem led to the development of the design shown in Figure 5. It required less area for any design speed than any other design studied and was done with only five bridges. However, four of these bridges had a high degree of skew and not until the "single-column" type of bridge entered the study did it seem practical at all. The reason for discarding this design was lack of transition on the right and left turns. One advantage though that might be mentioned here is that both the right and left turns can be made on a horizontal grade and be brought as close together as desired, provided that the shifting for through traffic, done by the skew bridge at the approach, is done far enough back in the right-of-way so as not to limit the grades to values above 5 percent.

SPIRAL-ROLL
Transitioned right and left

This is the design finally used and is the outgrowth of ideas gained in the study of all the other types. Essentially it is the same as that shown in Figure 5; but transition was employed on both ends of the right and left turns. This gave symmetry in design and simplicity in transit. Only one comment seems appropriate here, since the interchange will be discussed more fully in the pages that follow.

Depending upon the degree of the intersection where the through-traffic passes over the opposed-traffic, a lot can be done. This is the one thing that controls the entire design. For purposes of this work 30° was used as a design value and it seemed to have worked well. If you are willing to accept degrees below thirtythe area can be cut down and the two through-traffic lanes can be brought close enough together to make the elimination of the four bridges in the center possible and their replacement with one bridge capable of handling four lanes of traffic.

TYPE OF INTERSECTION

Express highways have been broadly defined as thoroughfares with opposing traffic streams separated, with grade separation eliminating all or a large part of congestion caused by cross traffic, with controlled entry and exit points and other facilities in varying degree for permitting large numbers of behicles to move steadily and safely.

The intersection is assumed to be between two two-lane divided express highways, intersecting at 90° or nearly so. The proposed design is of such form that any excessive volume of flow in any one direction as shown by the traffic survey of the particular site under consideration can be allowed for by merely adding additional traffic lanes in that direction without having to change the basic design or restudy the problem.

The right hand turns are designed for a speed of fifty miles per hour on a level grade, using transition at both ends. To make the right turn the driver simply stays in the right lane on the approach to the interchange and follows on to the right as signs will indicate.

To make the left hand turns, the driver stays in the left lane on the approach to the interchange, passes over the opposed-traffic lanes with the through-traffic and merely bears left as indicated by signs along the side of the road or on the road surface itself. The left hand turns are designed for the same speed as the right hand turn; but a down grade of 2 percent is used.

The through-traffic of the two highways is accommodated at different elevations to avoid interference. It is assumed that speeds on the highway coming to the interchange will be in the neighborhood of seventy miles per hour, the curves which form the approach to the interchange are designed for a speed of sixty

miles per hour to cause the traffic to slow while passing through the interchange and to avoid an abrupt slow down for those wishing to go to the right or left, which if allowed, would in turn cause the through traffic to slow down.

The main highways consist of four lanes each being twelve feet wide, separated in pairs by a central dividing strip when passing close together, otherwise, considered as separate highways and taking advantage of any topographical features of the area under consideration.

The approaches to the interchange are considered to be within the limits of the right-of-way standards recommended by Appendix 5, House Document No. 379 on the "Basic Standards for Road and Structural Design of Interregional Highways".

The widths of turns are designed for one traffic lane and it is assumed that the cars will pass from the through-traffic lanes in single file, at the rate and spacing upon which the theoretical capacity is based.

The work involved in this thesis includes: an analysis of several other designs studied before selecting a final design to complete, the complete design of the horizontal and vertical alignment.

Speed perhaps is one of the most important factors to be considered since all economic analysis involves speed one way or another. Either by loss due to conjestion, lack of ability to make time, or the gain from saving time.

More important in another sense is safety for without complete safety at design speed the interchange would be of no use whatever. Using a speed of 50 miles per hour as a minimum design speed throughout the interchange gave long sweeping curves that have transition at each end to give easy change of direction to the driver without discomfort. Although these curves eliminated the possibility of a compact design

the right and left turns would appear to be concentric and the area between them could probably be utilized to good advantage by commercial interests for super-markets, hot-shoppes, drive-ins, filling stations and the like. In fact, the interchange might in time develope into an ultra-modern suburban shopping center and thus justify part of the initial construction costs as well as provide a tax base more than enough to adequately maintain it.

Symmetry was maintained in both horizontal and vertical alignment with the exception of the through-traffic lanes where two are over and two under. The "basket-weave" could have been used here to give symmetry in vertical alignment but the area required to keep slopes within the allowed 5 percent would have been prohibitive.

Continuous flow of traffic was considered to be an essential to the design but the curves were to act as a means of slowing a driver down to a "safe 50" when entering the interchange.

SITE LOCATION

The design as shown is not for any particular location, though it could easily enough be adapted to a location. Vertical alignment was computed on the basis of a zero datum plane.

For fairly level ground the cuts could be made to balance the fills and for other locations the vertical alignment could be modified so as to take advantage of any favorable topographic features.

DRAINAGE

Adequate drainage can be accomplished by proper grading of the slopes. Superelevation on curves, parabolic crown on the main roadway and the vertical grades will supply adequate drainage for the roads. In times of excessively heavy storms or heavy storms of short duration, it will be necessary to design the slopes of the ground inside the

through-traffic lanes for ponding.

Efficient drainage is important since the life of the highway depends upon it. In this type of design the drainage is of particular importance, otherwise the interchange might be completely flooded out in one direction.

The problem becomes somewhat involved in that the highways form many possible impounding areas which would have to be drained by the use of pipe to the outside drainage ditches alongside the highway or low spots near the interchange.

PAVEMENT DESIGN

No wearing surface was designed since it would be based only on assumed values and would serve no practical purpose in this work. The use of portland cement concrete slab pavement throughout the interchange is recommended.

MODEL CONSIDERATION

Time did not permit the completion of a model of the interchange as designed. The interchange is simple in design and not hard to see in volume after a bit of study; but a model would make such a design easier to understand and show the general appearance, solutions of details, size and proportioning of parts, needed treatment to secure appropriate surrounding topography and the overall plan and type of beautification and landscaping. Also a model would serve to give an estimator and contractor better ideas of what is expected of them and affect their bidding accordingly.

BRIDGE DESIGNS

Eight bridges are required in all. The four through-traffic bridges should be of the rigid-frame, reinforced-concrete type on account of their economy and adaptability to various architectural treatments.

The four skew bridges were at first considered to be the limiting factor in the adoption of this type of design. After reading Mr. Finke's article entitled "Single-Column Viaduct Eliminates Need for Skew Span", however, it appears that a similar type of structure could be designed for this purpose. Essentially it would be a roadway supported by only two columns with cantilevered ends. This would eliminate the use of retaining walls and the embankments could be graded to some desired slope to fit the general lanscape scheme.

By using 4 percent slopes on roadways at the approaches, enough elevation was gained to provide six feet vertical distance for the bridge structure floor and roadbed, giving a 14 foot minimum overhead clearance. Horizontal clearance to structures are recommended as follows: 3 feet to railings, 6 feet to abutments, piers and the like with few exceptions.

ESTIMATE OF COST

It is difficult to make any cost estimate for this type of design due to the variation in the cost of materials and labor. However, it is felt that the overall cost would not be as great as the four level design made by Gruman and Panchorst for use in California. They plan to spend $1,700,000 for the structure alone the design still has the main disadvantage of interchanges to date; namely, having to go right to make a left turn. There will be a saving in right-of-way cost by the use of this type of interchange and future savings in operating costs by the structures involved as compared to any other type are large enough to retire any immediate excess construction costs within a relatively short time.

HORIZONTAL ALIGNMENT

The horizontal curves for the interchange are all designed for high speed and have transition at both ends.

Approach curve	60 mph
Right Turn curve	50 mph
Straightaway curve	70 mph
Left Turn curve	50 mph
Exit curve	60 mph

The required radii for different speeds with considerations for superelevation were based on the formula:

$$S + F = \frac{0.067V^2}{R}$$

where, S = the superelevation in feet per foot of width.

V = the speed of vehicle in miles per hour.

R = the radius of the curve in feet.

F = the side friction factor

Using a maximum superelevation slope of 0.10 and a maximum safe factor for frictional resistance of 0.16, the minimum safe radius of curvature can be computed from the formula:

$$R = 0.258V^2$$

For speeds of 50 and 60 miles per hour, curves with radii less than 644 and 928 feet, respectively, should not be used. These correspond to curves of 8.9° and 6.2°, respectively. For a speed of 70 miles per hour, a lower friction factor of 0.14 and a maximum superelevation slope of 0.10 result in a minimum safe radius of 1370 feet, radius corresponding to a curvature of 4.2°.

It has been common practice to superelevate pavements on curves to counteract all the centrifugal force of a vehicle traveling at an assumed speed. Because of practical limitations on the amount of superelevation it is not possible to compensate fully for

centrifugal force on sharp curves as it becomes necessary to rely upon friction, in addition to superelevation, to prevent a vehicle from sliding outward.

The superelevation values are based on the assumption that all centrifugal force resulting from a speed of three-fourths of the design speed is counteracted by the effects of superelevation up to a maximum practicable limit of 0.10 foot per foot of width.

On highways without transitions the average driver traveling at the maximum speed for which a curve is designed finds it difficult to confine his vehicle to his traffic lane and maintain a uniform speed around the curve. This encroachment on adjacent traffic lanes creates a traffic hazard both to the driver and to others.

To avoid this hazard transition curves are employed at both ends of all curves, enabling the driver to maintain a uniform speed around the curve and at the same time, encourage him to keep within his own traffic lane.

The transitions as designed are considered to be long enough so that at the speed for which the curves are designed, the driver is allowed enough time to change from a straight to a circular motion by turning his wheels gradually and to swing into the circular part of the curve within the limits of the occupied lane. At the same time the driver feels the development of the centrifugal force gradually, causing no discomfort.

The required length of transition is based on the following formula:

$$L_s = 1.6\frac{V^3}{R}$$

where, L = the length of the spiral in feet.

V = the speed of the vehicle in miles per hour.

R = the radius of the curve in feet.

Widening of the curves was based on the formula:

$$W = 2(R - (R^2 - L^2)^{\frac{1}{2}}) + \frac{35}{(R)^{\frac{1}{2}}}$$

where, W = the widening of the roadway in feet.

R = radius of the curve in feet.

L = the length of the wheel base of the vehicle in feet.

Using a wheel base of 20 feet, as recommended by the American Association of State Highway Officials' committee on road design, and replacing the 35, which is probably a design speed, with V, the following formula is derived.

$$W = n(R - (R^2 - 400)^{\frac{1}{2}}) + \frac{V}{R^{\frac{1}{2}}}$$

where, n = the number of lanes under consideration.

The above formula was recommended by Mr. Joseph Barnett in his "Transition Curves for Highways". He further states, "Present practice regarding the degree of curvature below which no widening is required varies between 5° and 6°-8°. It is suggested that no pavement requiring less than 2 feet of widening in accordance with the formula be widened. This results in no widening on two-lane pavements on curves flatter than:

4°	for	70 mph
5°	for	60 mph
and 6°	for	50 mph."

Tests and observations of driving habits indicate that for safe and comfortable driving a traffic lane should be at least 11 feet wide. Since the author chose to use a twelve foot width in the design, it will be necessary to widen the single lanes for right and left turns to 13 feet.

Theoretical capacity of traffic lanes was computed by a formula recommended by Mr. John H. Bateman in his text, Highway Engineering.

$$N = \frac{5280S}{C + L}$$

where, N = the number of vehicles per hour.

S = the speed of the vehicles in miles per hour.

C = the clearence between two consecutive vehicles in feet.

L = the length of vehicle, in feet.

Although Mr. Bateman has recommended the assumption of 15 feet as the average length of vehicles, the Consumers Research Analysis of June this year shows the 1947 passenger cars to have an average length of approximately 18 feet. With the advent of the truck-trailer for commercial purposes on the highways and this increase in the length of passenger cars in mind, the author has selected 18 feet to be used as a design value.

The maximum safe theoretical capacity for one traffic lane is based on the formula:

$$S = \frac{Vt}{1.5} + \frac{V^2}{4.5a}$$

where, S = the stopping distance in feet.

V = the speed of the vehicle, at the time of observing the obstacle, in miles per hour.

t = the total reaction time of the driver in seconds.

a = the rate of deceleration of the vehicle, in feet per second per second.

for computing the clearence between two consecutive vehicles, since this clearence is assumed for design purposed to be equal to the minimum stopping distance.

The stopping distance of a vehicle depends upon the sight reaction time of the driver and the brake reaction time. For purposes of this design a reaction time of 4 seconds is assumed and a deceleration rate of 9 feet per second per second is used,

as recommended by Mr. Bateman. This resulted in the following values: for

50 mph	195 feet
60 mph	249 feet
70 mph	308 feet

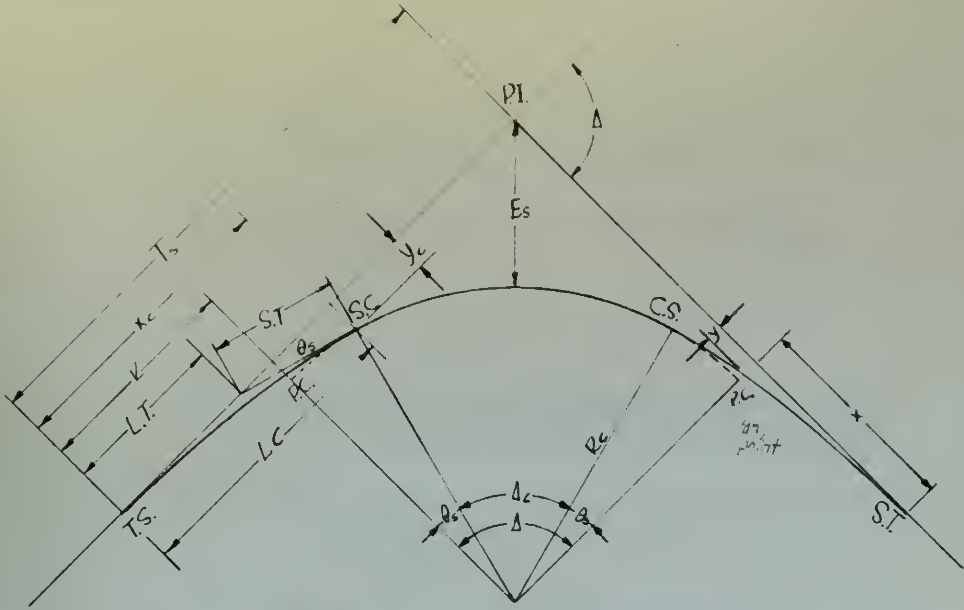
Using the above values for clearence between two consecutive vehicles in Bateman's formula, the following capacities were obtained:

50 mph	1240 cars/hour/lane
60 mph	1190 cars/hour/lane
70 mph	1140 cars/hour/lane

The through-traffic lanes are 2745.66 feet long, right-traffic lanes are 1188.88 feet long and left-traffic lanes 966.67 feet long.

The overall horizontal alignment wasmade in accordance with the recommended standards of Mr. Joseph Barnett's "Transition Curves for Highways", whose main object in writing the book and designing the tables was to make it as simple and inexpensive as possible to design and locate curves with transition as used in highway design.

Without such a simple method for computing the horizontal alignment, it would have been impossible to have studied so many interchange designs and modifications in the time available for the work.



Curve with transition—both ends.

TRANSITION SYMBOLS

P.I.	Point of intersection of the main tangents.
T.S.	Tangent spiral, common point of tangent and spiral of near transition.
S.C.	Spiral curve, common point of spiral and circular curve of near transition.
C.S.	Curve spiral, common point of circular curve and spiral of far transition.
S.T.	Spiral tangent, common point of spiral and tangent of far transition.
R_c	Radius of the circular curve.
L_s	Length of spiral between T.S. and S.C.
L	Length between T.S. and any other point on spiral.
T_s	Tangent distance P.I. to T.S. or S.T., or tangent distance of the complete curve.
E_s	External distance P.I. to center of circular curve portion, or to the S.C.S. of a curve transitional throughout.
S.C.S.	Spiral curve spiral, common point of both spirals or midpoint of a curve transitional throughout.
L.T.	Long tangent distance of spiral only.
S.T.	Short tangent distance of spiral only.
L.C.	Straight line chord distance T.S. to S.C.

p Offset distance from the tangent of P.C. of circular curve produced.

k Distance from T.S. to point on tangent opposite the P.C. of the circular curve produced.

Δ Intersection angle between tangents of entire curve.

Δ_c Intersection angle between tangents at the S.C. and at the C.S. or the central angle of the circular curve portion of the curve.

θ_s Intersection angle between the tangent of the complete curve and the tangent at the S.C., the spiral angle.

θ Intersection angle between the tangent of the complete curve and the tangent at any other point on the spiral, the spiral angle of any other point.

D_c Degree of the circular curve same as degree of curvature of spiral at the S.C. (arc definition).

D Degree of curvature of spiral at any other point on spiral (arc definition).

ϕ_c Deflection angle from tangent at T.S. to S.C.

ϕ Deflection angle from tangent at any point on spiral to any other point on spiral.

x_c, y_c Coordinates of S.C. and measured from the T.S.

x, y Coordinates of any other point on spiral from the T.S.

FUNCTIONS OF TRANSITIONS

	Approach	Right	Straightaway	Left	Exit
Δ	20°	80°	30°	60°	20°
S	60mph	50mph	70mph	50mph	60mph
D_c	5°	9°	4°	9°	5°
T_s	352.55'	688.85'	584.92'	520.67'	352.55'
E_s	21.00'	202.10'	55.40'	105.30'	21.00'
L_s	300.00'	300.00'	400.00'	300.00'	300.00'
Δ_c	5°	53°	14°	33°	5°
L_c	100.00'	588.88'	350.00'	366.67'	100.00'
R	1146.00'	637.00'	1432.00'	637.00'	1146.00'
W	24.00'	13.00'	24.00'	13.00'	24.00'
θ_s	7.50°	13.50°	8.00°	13.50°	7.50°
p	3.27'	5.88'	4.65'	5.88'	3.27'
k	149.91'	149.72'	199.87'	149.72'	149.91'
x_c	299.49'	298.34'	399.22'	298.34'	299.49'
y_c	13.07'	23.47'	18.59'	23.37'	13.07'
L.T.	200.18'	200.58'	266.94'	200.58'	200.18'
S.T.	100.16'	100.53'	133.58'	100.53'	100.16'
L.C.	299.77'	299.26'	399.65'	299.26'	299.77'

APPROACH CURVE

	Station	Deflection Angle
P.I.	89 64.70	
T.S.	86 17.25	
1	86 47.25	0-01.6
2	86 77.25	0-06.0
3	87 07.25	0-13.6
4	87 37.25	0-24.0
5	87 67.25	0-37.6
6	87 97.25	0-54.6
7	88 27.25	1-13.6
8	88 57.25	1-36.0
9	88 87.25	2-01.6
S.C.	89 17.25	2-30.0
C.C.	89 67.25	
S.C.	90 17.25	2-30.0
9	90 47.25	2-01.6
8	90 77.25	1-36.0
7	91 07.25	1-13.6
6	91 37.25	0-54.6
5	91 67.25	0-37.6
4	91 97.25	0-24.0
3	92 27.25	0-13.6
2	92 57.25	0-06.0
1	92 87.25	0-01.6
S.T.	93 17.25	

RIGHT TURN CURVE

	Station	Deflection Angle
P.I.	97 89.11	
T.S.	91 00.26	
1	91 30.26	0-02.8
2	91 60.26	0-10.8
3	91 90.26	0-24.4
4	92 20.26	0-43.2
5	92 50.26	1-07.6
6	92 80.26	1-37.2
7	93 10.26	2-12.4
8	93 40.26	2-52.8
9	93 70.26	3-38.8
S.C.	94 00.26	4-30.0
C.C.	96 94.44	
C.S.	99 89.14	4-30.0
9	100 19.14	3-38.8
8	100 49.14	2-52.8
7	100 79.14	2-12.4
6	101 09.14	1-37.2
5	101 39.14	1-07.6
4	101 69.14	0-43.2
3	101 99.14	0-24.4
2	102 29.14	0-10.8
1	102 59.14	0-02.8
S.T.	102 89.14	

STRAIGHTAWAY

	Station		Deflection Angle
P.I.	100	00.00	
T.S.	94	15.08	
1	94	55.08	0-01.6
2	94	95.08	0-06.4
3	95	35.08	0-14.4
4	95	75.08	0-25.6
5	96	15.08	0-40.0
6	96	55.08	0-57.6
7	96	95.08	1-18.4
8	97	35.08	1-42.4
9	97	75.08	2-09.6
S.C.	98	15.08	2-40.0
C.C.	99	40.08	
C.S.	101	65.08	2-40.0
9	102	05.08	2-09.6
8	102	45.08	1-42.4
7	102	85.08	1-18.4
6	103	25.08	0-57.6
5	103	65.08	0-40.0
4	104	05.08	0-25.6
3	104	45.08	0-14.4
2	104	85.08	0-06.4
1	105	25.08	0-01.6
S.T.	105	65.08	

LEFT TURN CURVE

	Station	Deflection Angle
P.I.	99 14.52	
T.S.	93 93.85	
1	94 23.85	0-02.8
2	94 53.85	0-10.8
3	94 83.85	0-24.4
4	95 13.85	0-43.2
5	95 43.85	1-07.6
6	95 73.85	1-37.2
7	96 03.85	2-12.4
8	96 33.85	2-52.8
9	96 63.85	3-38.8
S.C.	96 93.85	4-30.0
C.C.	98 97.18	
C.S.	100 60.52	4-30.0
9	100 90.52	3-38.8
8	101 20.52	2-52.8
7	101 50.52	2-12.4
6	101 80.52	1-37.2
5	102 10.52	1-07.6
4	102 40.52	0-43.2
3	102 70.52	0-24.4
2	103 00.52	0-10.8
1	103 30.52	0-02.8
S.T.	103 60.52	

EXIT CURVE

	Station	Deflection Angle
P.I.	110 15.46	
T.S.	106 62.91	
1	106 92.91	0-01.6
2	107 22.91	0-06.0
3	107 52.91	0-13.6
4	107 82.91	0-24.0
5	108 12.91	0-37.6
6	108 42.91	0-54.6
7	108 72.91	1-13.6
8	109 02.91	1-36.0
9	109 32.91	2-01.6
S.C.	109 62.91	2-30.0
C.C.	110 12.91	
C.S.	110 62.91	2-30.0
9	110 92.91	2-01.6
8	111 22.91	1-36.0
7	111 52.91	1-13.6
6	111 82.91	0-54.6
5	112 12.91	0-37.6
4	112 42.91	0-24.0
3	112 72.91	0-13.6
2	113 02.91	0-06.0
1	113 32.91	0-01.6
S.T.	113 62.91	

All longitudinal slopes are to be less than 5%.

Where two grades connect, the grade line is rounded off by the utilization of a vertical curve. The parabola is used for the vertical curves in this design since its mathematical properties make the ordinate computations simple.

Usually sight distance is considered to be an important factor in determining the length of a vertical curve, however, the design, in this case, is such that the small grades and traffic only in one direction precludes any consideration of minimum sight distance since the danger of a head on collision is impossible and if traffic is flowing at designed speed there should be little desire to or few attempts made to pass cars while in the interchange proper.

Minimum non-passing sight distances recommended by the National Interregional Highway Committee for the design speeds considered are as follows:

70 mph	700 feet
60 mph	525 feet
50 mph	400 feet

The designs are within those limits.

The formula used for the length determination of vertical curves is

$$L = \frac{l^2 G}{8h}$$

where,
- G = total change of grade in percent.
- L = the minimum length of vertical curve in stations.
- l = sight distance in stations.
- h = vertical height in feet in the line of sight above the roadway, assumed the same for two vehicles going toward each other, usually taken as 5 feet.

In view of the present trend toward lower heights of eye, 4 feet was

was used throughout the design.

To compute the ordinates of the parabolic vertical curves the vertical distance from the intersection of the grade tangents to the midpoint of the curve was computed by the following formula:

$$H = \frac{G_1 - G_2}{8} \times \frac{L}{100}$$

where, H = the vertical distance, in feet, from the intersection of the grade tangents to the midpoint of the curve.

$G_1 - G_2$ = the algebraic difference, in per cent, between the two intersecting grades, always expressed as a positive number.

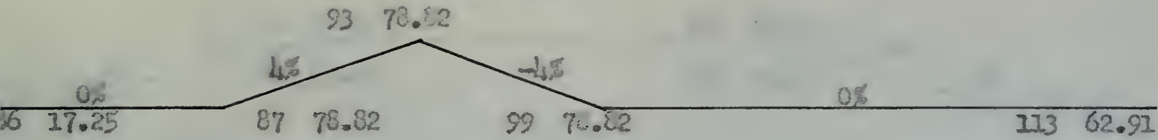
L = the length of the curve, in feet.

The minimum vertical clearance under the bridges is taken as 14 feet as recommended by the American Association of State Highway Officials; "Standard Specifications for Highway Bridges".

The United States Bureau of Public Roads recommends that curve compensation be made on grades over five percent on all curves of a radius shorter than 200 feet and at the rate of 1 percent per 50 feet reduction in radius.

Since there is more resistance to motion on a curve than on a tangent, and consequently for a certain working grade on a tangent, the corresponding grade on a curve should be corrected accordingly. By keeping slopes below 5 percent and radii greater than 200 feet this compensation was not necessary.

NORTH-SOUTH
Through Traffic

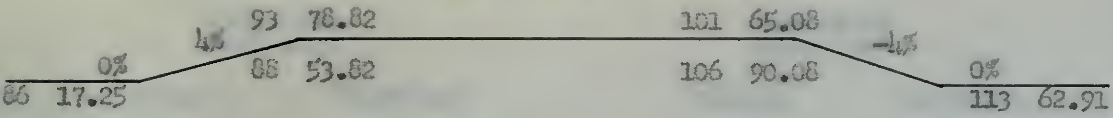


0% - 4%   L = 2 stations   H = 1 foot

4% - -4%   L = 4 stations   H = 4 feet

Station	Elevation	Station	Elevation
86 17.25	00.00	94 28.82	19.76
86 53.82	00.00	94 78.82	19.00
86 78.82	00.00	95 28.82	17.76
87 03.82	00.06	95 78.82	16.00
87 28.82	00.25	96 78.82	12.00
87 53.82	00.56	97 78.82	8.00
87 78.82	1.00	98 78.82	4.00
88 03.82	1.56	99 03.82	3.06
88 28.82	2.25	99 28.82	2.25
88 53.82	3.06	99 53.82	1.56
88 78.82	4.00	99 78.82	1.00
89 78.82	8.00	100 03.82	00.56
90 78.82	12.00	100 28.82	00.25
91 78.82	16.00	100 53.82	00.06
92 28.82	17.76	100 78.82	00.00
92 78.82	19.00	101 03.82	00.00
93 28.82	19.76	102 03.82	00.00
93 78.82	20.00	113 62.91	00.00

EAST-WEST
Through Traffic



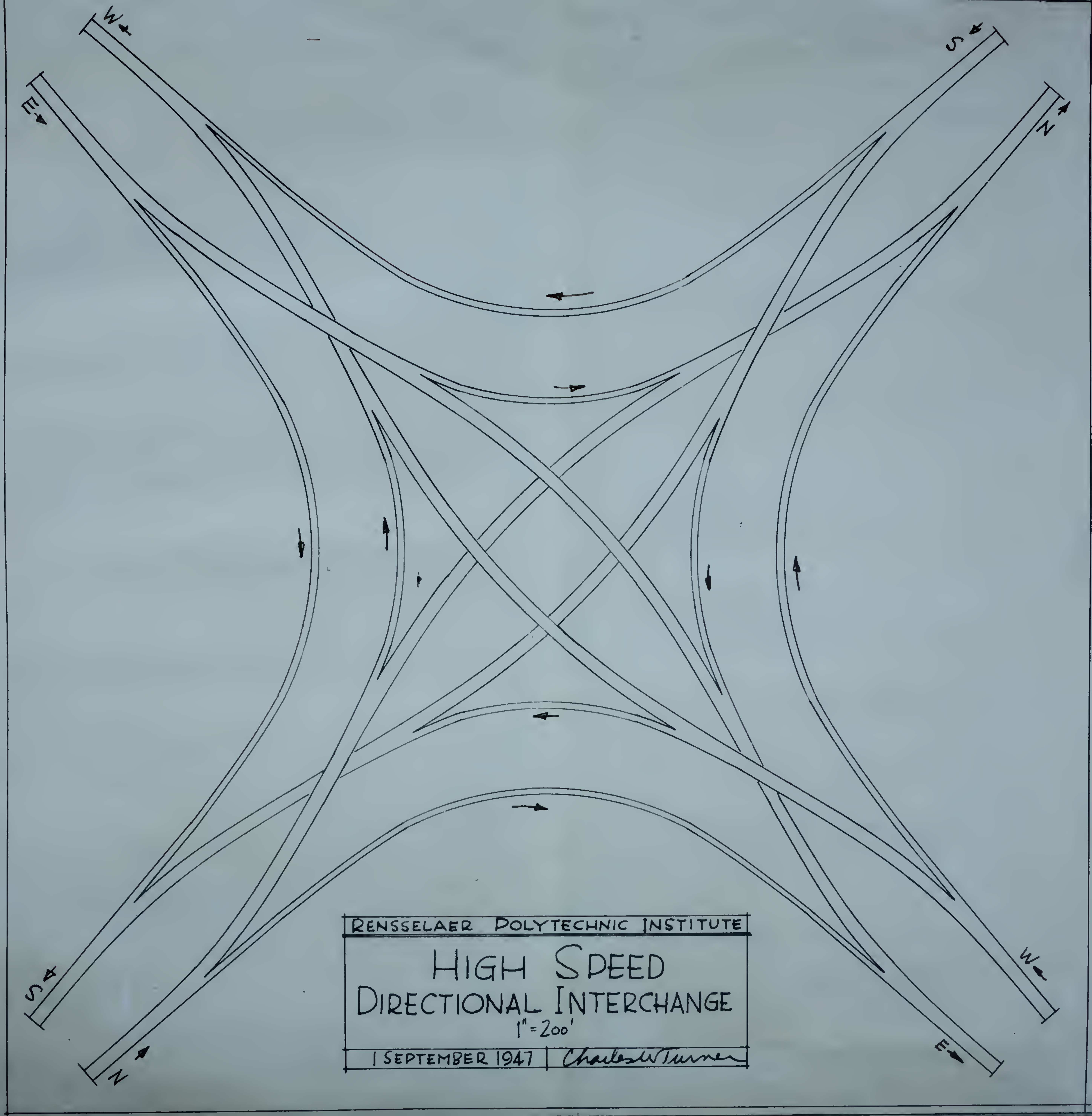
0% - 4% L = 2 stations H = 1 foot

0% - -4% L = 2 stations H = 1 foot

Station	Elevation	Station	Elevation
86 17.25	00.00	98 76.34	21.00
87 17.25	00.00	99 01.34	20.94
87 53.82	00.00	99 26.34	20.75
87 78.82	00.06	99 51.34	20.44
88 03.82	00.25	99 76.34	20.00
88 28.82	00.56	100 01.34	19.44
88 53.82	1.00	100 26.34	18.75
88 78.82	1.56	100 51.34	17.94
89 03.82	2.25	100 76.34	17.00
89 28.82	3.06	101 01.34	16.00
89 53.82	4.00	102 01.34	12.00
90 53.82	8.00	103 01.34	8.00
91 53.82	12.00	104 01.34	4.00
92 53.82	16.00	104 26.34	3.06
92 78.82	17.00	104 51.34	2.25
93 03.82	17.94	104 76.34	1.56
93 28.82	18.75	105 01.34	1.00
93 53.82	19.44	105 26.34	00.56
93 78.82	20.00	105 51.34	00.25
94 03.82	20.44	105 76.34	00.06
94 28.82	20.75	106 01.34	00.00
94 53.82	20.96	107 01.34	00.00
94 78.82	21.00	113 62.91	00.00

LEFT TURNS

North-West South-East Station		Elevation	East-North West-South Station		Elevation
93	78.82	20.00	93	78.82	20.00
94	28.82	19.76	93	03.82	20.44
94	78.82	19.00	93	28.82	20.75
95	28.82	17.76	93	53.82	20.96
95	78.82	16.00	93	78.82	21.00
96	78.82	14.00	94	28.82	21.00
97	78.82	12.00	94	53.82	20.96
98	78.82	10.00	94	78.82	20.75
98	97.18	9.60	95	03.82	20.44
99	75.25	8.00	95	28.82	20.00
100	75.25	6.00	95	53.82	19.44
101	75.25	4.00	95	78.82	18.75
102	00.25	3.06	96	03.82	17.94
102	25.25	2.25	96	28.82	17.00
102	50.25	1.56	67	03.82	16.00
102	75.25	1.00	98	03.82	12.00
103	00.25	00.56	99	03.82	8.00
103	25.55	00.25	100	03.82	4.00
103	50.55	00.06	100	28.82	3.06
103	75.55	00.00	100	53.82	2.25
			100	78.82	1.56
			101	03.82	1.00
			101	28.82	00.56
			101	53.82	00.25
			101	78.82	00.06
			102	03.82	00.00
			103	03.82	00.00
			103	75.55	00.00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RENSSELAER POLYTECHNIC INSTITUTE
HIGH SPEED
DIRECTIONAL INTERCHANGE
1" = 200'
1 SEPTEMBER 1947
Charles W Turner

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